CHAPTER 12

MECHANICAL AND ELECTRICAL EQUIPMENT

12-1. Introduction. This chapter prescribes the criteria for structural design of anchorages and supports for mechanical and electrical equipment in seismic areas.

a. Design goals. The goal of design is that the anchorages and supports will withstand the accelerations induced by severe seismic disturbances without collapse or excessive deflection and withstand the accelerations induced by less severe seismic disturbances without exceeding yield stresses. The design forces are related to the inertia forces on the equipment and are calculated on the weight of the equipment; accordingly, design provisions often speak of equipment. However, the design is for the supports of the equipment, not the equipment itself. Ordinary equipment, which is fabricated at some distance from the site and is transported by truck and/or railroad, is assumed to have adequate strength. Critical equipment, which may have to be substantiated by design or test, is beyond the scope of this manual.

b. Seismic forces. The design force coefficients applied to equipment supports are generally higher than the force coefficients used in the design of buildings. One reason is the amplification of the ground motion acceleration transmitted to elements in the elevated stories of a building due to dynamic response. Another reason is that equipment supports often lack the extra margin of safety provided by reserve strength mechanisms, such as participation of architectural elements, inelastic behavior of structural elements, and redundancy in the structural system, that are characteristic of buildings.

12-2. General. All equipment anchorages and supports designed under the provisions of this chapter will conform to the following requirements:

a. Rigid and/or rigidly supported equipment. Rigid equipment that is rigidly attached to the structure will be designed for seismic forces prescribed by SEAOC 1G. Limitations, exceptions, and commentary are stated in paragraph 12-3.

b. Nonrigid or flexibly supported equipment. Nonrigid or flexibly supported equipment will be designed with consideration given both to the dynamic properties of the equipment and to the building or structure in which it is placed. For equipment supported by a structure and located above grade on a structure, SEAOC 1G2c will be modified by the procedure outlined in paragraph 12-4.

c. Equipment on the ground. Equipment supported on the ground will be designed in accordance with SEAOC 1G as supplemented by paragraph 12-5.

d. Weight limitations. Equipment in buildings will be considered to be within the scope of this chapter if the maximum weight of the individual item of equipment does not exceed 10 percent of the total building weight or 20 percent of the total weight of the floor at the equipment level. The response of equipment is dependent upon the response of the building in which it is housed. If the weight of the equipment is appreciable, relative to the weight of the building, the interaction of the equipment with the building (i.e., the coupling effect) will change the building response characteristics. It is assumed that equipment within the above weight limitations has a negligible effect on the response of the building. Equipment that is not within the above limitations is outside the scope of this manual and must be designed using a more rigorous method of analysis.

e. Rigorous analysis. No portion of this chapter will be construed to prohibit a rigorous analysis of equipment and the supporting mechanism by established principles of structural dynamics. Such an analysis will demonstrate that the fundamental principle and underlying criterion of paragraph 12-1 are satisfied. In no case will the design result in capacities less than 80 percent of those required by SEAOC 1G.

f. Securing equipment. Friction resulting from gravity loads as a method of resisting seismic forces is not acceptable and will not be allowed. Both vertical and horizontal accelerations are possible during an earthquake. Under vertical acceleration, the gravity force required to maintain friction can be greatly diminished. This could result in a reduction of the friction force available to resist horizontal seismic loads, as simultaneous vertical and horizontal accelerations are possible. Thus, equipment will be secured by bolts, embedment, or other acceptable positive means of resisting horizontal forces. Refer to paragraph 12-11 for typical details.

g. Special requirements. Requirements for lighting fixtures and supports, piping, stacks, bridge cranes and monorails, and elevator systems are covered in paragraphs 12-6 through 12-10, respectively.

12-3. Rigid and/or rigidly supported equipment in buildings. This paragraph applies to equipment above grade. See paragraph 12-5 for equipment supported at or below grade. Rigid and/or rigidly supported equipment will be considered to be those equipment units and equipment supporting systems for which the period of vibration as defined in paragraph 12-4*b* is estimated to be less than 0.06 second (i.e., frequency of vibration greater than 17 Hz). Compact equipment directly attached to a concrete floor will be considered rigidly supported. This type of equipment-supporting system is very stiff, and the period of vibration is very short (i.e., there is a high frequency of vibration). Equipment not satisfying the rigidity requirement will be designed according to the criteria of paragraph 12-4.

a. Examples of rigidly mounted equipment.

(1) A boiler bolted or otherwise securely attached to a concrete pad or directly attached to the floor of the structure.

(2) An electrical panel board securely attached to solid walls or to the studs of stud walls.

(3) An electric motor bolted to a concrete floor.

(4) A floodlight having a short stem bolted to a wall.

(5) A rigidly anchored heat exchanger.

b. Equivalent static force. The equivalent static lateral force is given by SEAOC equation 1-10. C_p, as prescribed in SEAOC Table 1-H, is equal to 0.75 for all equipment and machinery that is rigid and rigidly supported by the building (see para 12-5 for equipment on the ground). For cantilevered portions of chimneys and smokestacks, C_p is 2.0; however, these items must also be investigated for the criterion stated in paragraph 12-8.

12-4. Nonrigid or flexibly supported equipment in buildings. This paragraph applies to equipment above grade. See paragraph 12-5 for equipment supported at or below grade. Equipment that does not satisfy the rigidity requirements of paragraph 12-3 will be considered to be nonrigid or flexibly supported. For nonrigid and flexibly supported equipment, the appropriate seismic design forces will be determined with consideration given to both the dynamic properties of the equipment and to the building or structure in which it is placed (SEAOC 1G2c). An approximate procedure, which considers these dynamic properties within certain limits, is presented below. This approximate procedure is deemed to meet the SEAOC requirements. Nonrigid or flexibly supported equipment that does not qualify within the limits of this chapter is outside the scope of this manual and will be designed using a more rigorous method of analysis.

a. Single-mass system. The approximate procedure is based on the equipment responding as a single-degree-of-freedom system to the motion of one of the predominant modes of vibration of the building at the floor level in which the equipment is placed. Therefore, if the equipment and its supporting system cannot be approximated by a single-degree-of-freedom system (i.e., a simple oscillator represented by a single mass and a simple spring), a more rigorous analysis is required. Some examples of systems that do qualify under this procedure follow:

(1) Rigid equipment attached to the floor slab with a spring isolation system.

(2) Rigid equipment rigidly attached to a flexible supporting system that is rigidly attached to the floor slab.

(3) Rigid equipment attached by a cantilever support from the structure.

(4) Nonrigid equipment that can be represented as a single-mass system and that is rigidly attached to the structure.

EXCEPTIONS: Equipment that can be considered to have uniformly distributed mass will be designed for seismic forces in a manner similar to stacks (para 12-8).

b. Equipment period estimation. For equipment responding as a single-degree-of-freedom system, the period of vibration, T_a, is equal to 2π times the square root of the quantity mass/stiffness. In terms of inch and pound units, this equation becomes where

$$T_a = 2\pi\sqrt{\frac{W/g}{k}} = 0.32\sqrt{\frac{W}{k}} \qquad \text{(eq 12-1)}$$

T_a = fundamental period (sec)

k = stiffness of supporting mechanism in terms of load per unit deflection of the center of gravity (lb/in.)

W= weight of equipment and/or equipment supports (lb), which is equal to the mass times the acceleration of gravity

g = acceleration of gravity at 386 in./sec^2

In lieu of calculating the period of vibration using equation 12-1, a properly substantiated experimental determination will be allowed.

c. Building period estimation. If a building has more than one story it is considered to be a multi-degree-of-freedom system with more than one mode of vibration. Flexible equipment located in the building can be excited to respond to any of the predominant modes of the building vibration. Therefore, when investigating the response of equipment to the floor motion response, all predominant modes of vibration must be considered. The building parameters will be based on realistic estimations that are not restricted to limitations used in building design criteria.

(1) *Fundamental mode of vibration.* The fundamental period of the building vibration T_1 corresponds to the period T used in the design of the building. A realistic estimation of T_1 will be obtained from SEAOC Method B as illustrated by SEAOC equation 1-5.

(2) *Higher modes of vibration.* In addition to the fundamental mode of vibration, the predominant higher modes of vibration must be considered.

(a) For regular structures (SEAOC 1E4) with fundamental periods less than 2 seconds, include the second and third modes of vibration (translational modes in the direction under consideration). In lieu of a detailed analysis, the second-mode period of vibration may be assumed to equal 0.30 times the fundamental period of vibration (i.e., $T_2 = 0.30\ T_1$) and the third-mode period of vibration may be assumed to equal 0.18 times the fundamental period of vibration (i.e., $T_3 = 0.18\ T_1$).

(b) For buildings with fundamental periods greater than 2 seconds, the fourth mode and possibly the fifth mode should also be included.

(c) For irregular buildings, the dynamic characteristics of the structure must be investigated to determine other (nontranslational or torsional) predominant modes.

(d) In some cases, the vertical modes of vibration should be considered. This applies to floor systems that are flexible in the vertical direction and equipment sensitive to vertical accelerations.

d. Appendage magnification factor. The appendage magnification factor (MF) is the ratio of the peak motion of the appendage (in this case, equipment) to the peak motion of the floor level that it is mounted on. A theoretical value of the MF is generally based on steady-state motion due to the floor responding as a uniform sine wave. However, buildings that are responding to earthquakes move in a somewhat random fashion and thereby do not generate magnification factors as large as calculated by theoretical steady-state response. Following are discussions of the steady-state response and of an approximate method for estimating appendage magnification factors.

(1) The magnification factor for an idealized single mass oscillator, with a period T_a and damping characteristics at 2 percent of critical damping, responding to a steady-state sinusoidal acceleration having a period T, is plotted in figure 12-1. If T_a is essentially equal to T, MF equals 25. In other words, at a condition of resonance, the maximum acceleration of the oscillator mass will be 25 times the peak acceleration of the forcing motion. This idealized condition depends on the fine-tuning of the two periods, the linearity of the oscillator spring, the uniformity of the input sinusoidal motion, and the length of time of the input motion (at least 25 cycles).

(2) If the oscillator represents the equipment, the floor response represents the steady-state input motion, and the product ZC_p (0.4 x 0.75) equal to 0.30 is assumed to be the floor acceleration, the peak acceleration for the equipment is 25 times 0.30g = 7.5g. In other words, the horizontal force on the equipment is seven and one-half times its own weight. However, because of the actual nonlinear characteristics of equipment and buildings and particularly the finite duration of earthquake motion, it is highly unlikely that such a magnification could actually occur to a 2-percent-damped equipment appendage.

(3) In order to approximate a realistic value for a design MF, it is assumed that the periods T_a and T will differ by at least 5 percent; that buildings are not perfectly linearly elastic, especially at high amplitudes of response; that the floor response is not an exact, uniform sine wave; and that the number of high-amplitude floor response cycles is substantially less than 25.

(4) The design MF curve shown in figure 12-2 is presented as an aid to estimating the design response of single-degree-of-freedom appendages, in lieu of more rigorous analysis methods. The peak MF of 25 is reduced to 7.5 by reducing the effectiveness of the period tuning, the peak floor response amplitude, and the number of continuous cycles to roughly two-thirds of the idealized values (i.e., 25 × **b** × **b** × **b** = 7.5). The width of the magnification factor is broadened to account for uncertainty of actual period ratios.

e. Equivalent static force. The equivalent static force for the anchorage of flexible and flexibly mounted equipment is given by the equation

$$F_p = ZI_pA_pC_pWp \qquad \text{(eq 12-2)}$$

which is a modification of the SEAOC rigid equipment equation 1-10, where A_p is the amplification factor for a value of $C_p = 0.75$. The value of A_p is related to the MF values of figure 12-2; however, the maximum value of 7.5 is reduced to a value of 5.0 to account for multimode effects that are assumed to be included in the C_p values of SEAOC Table 1-H (i.e., the C_p value for rigid equipment considers the peak floor acceleration for a combination of modes; however, only one of these modes will excite the single resonance frequency of the

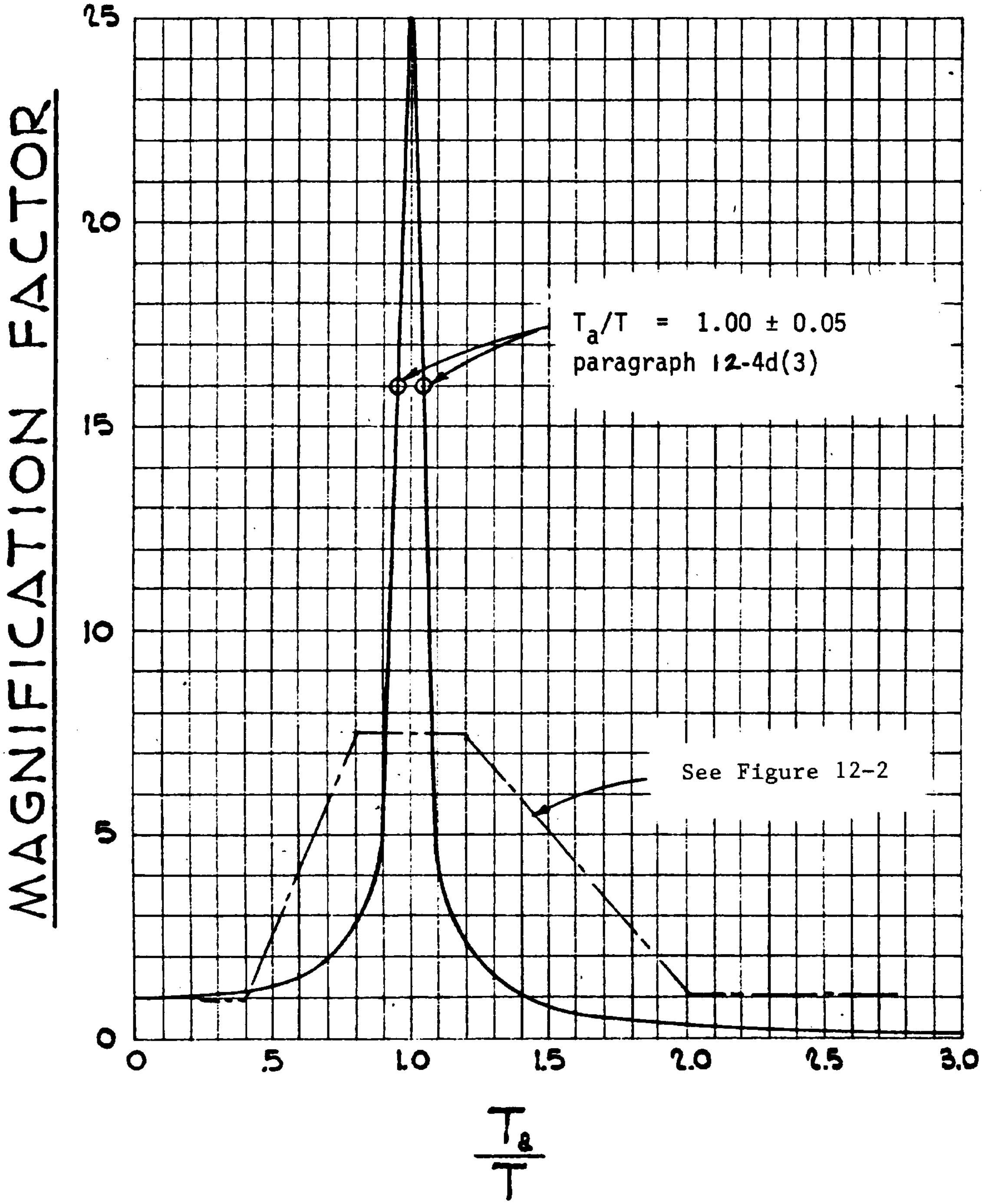


Figure 12-1. Idealized acceleration magnification factor vs period ratio at 2 percent of critical damping.

flexibly mounted equipment). The value of A_p will be determined by one of the alternatives listed below:

(1) If the periods of the building and equipment are not known, A_p = 5.0.

(2) If the fundamental period of the building is known but the period of the equipment is not known, A_p is determined by table 12-1.

(3) If building and equipment periods are both known, A_p may be approximated by the graphs in figure 12-3.

f. Use of the equivalent-static-force procedure. The force F_p of equation 12-2 will be applied in the same manner as the force F_p for rigid equipment in SEAOC 1G. The value of $I_pA_pC_p$ need not exceed 3.75, and in no case will the product A_pC_p be less than the appropriate C_p in SEAOC Table 1-H (i.e., if C_p = 2.0, A_p has an equivalent value of 2.67). As an aid to determining the A_p value, the following examples are given.

(1) A standard anchorage system is to be designed for some flexible equipment that will be

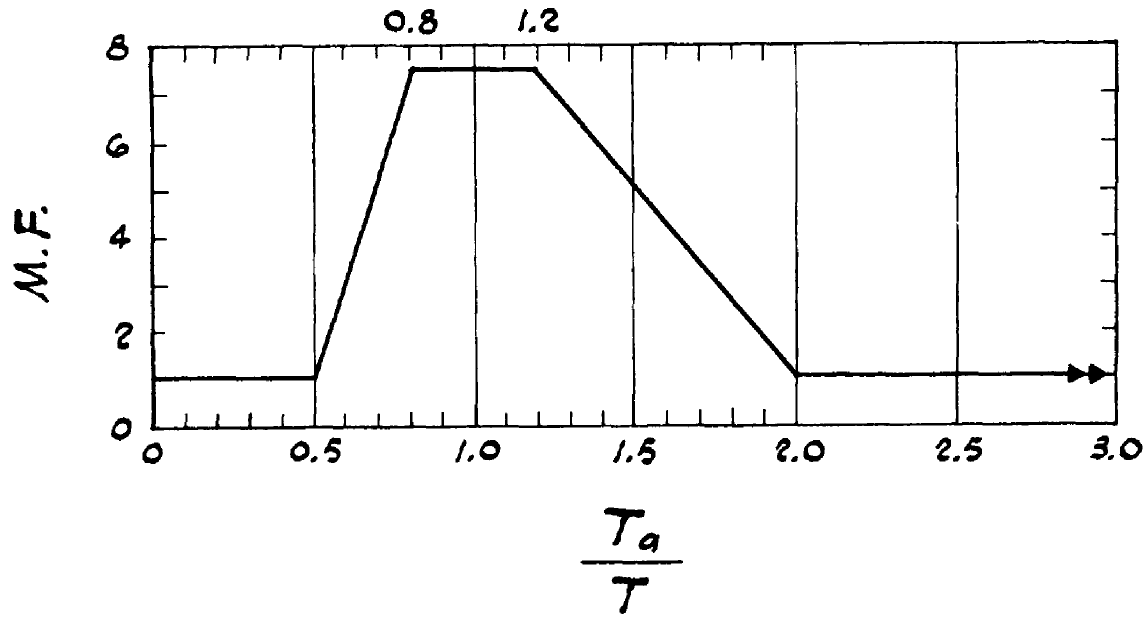


Figure 12-2. Design MF vs period ratio.

Building period T, sec	Less than 0.5	0.75	1.0	2.0	Greater than 3.0
A_p	5.0	4.75	4.0	3.3	2.7

***The values for A_p are based on a modal analysis using the period estimates of paragraph 12-4c, the design magnification factors of paragraph 12-4d, and a fairly standard response spectrum shape. The values in table 12-1 apply to regular structures or framing systems.**

Table 12-1. Amplification factor, A_p, for nonrigid or flexibly supported equipment.

placed in several buildings. In order to have one universal anchorage system that will apply to all buildings, use A_p equal to 5.0.

(2) An anchorage system is to be designed for some flexible equipment that will be placed in a building with a fundamental period of less than 0.5 second. Because the period of the equipment is not given, use table 12-1. A_p = 5.0.

(3) An anchorage system is to be designed for some flexible equipment that will be placed in a building with a fundamental period of roughly 1.4 seconds. Because the period of the equipment is not given, use table 12-1. Interpolate between 1.0 second and 2.0 seconds. A_p = 3.7.

(4) An anchorage system is to be designed for equipment with a period T_a equal to 0.2 second.

(a) In a building with T = 0.5 second. Because both the building period and equipment period are known, use graph (a) in figure 12-3. T_a/T = 0.2/0.5 = 0.4, and A_p = 2.7.

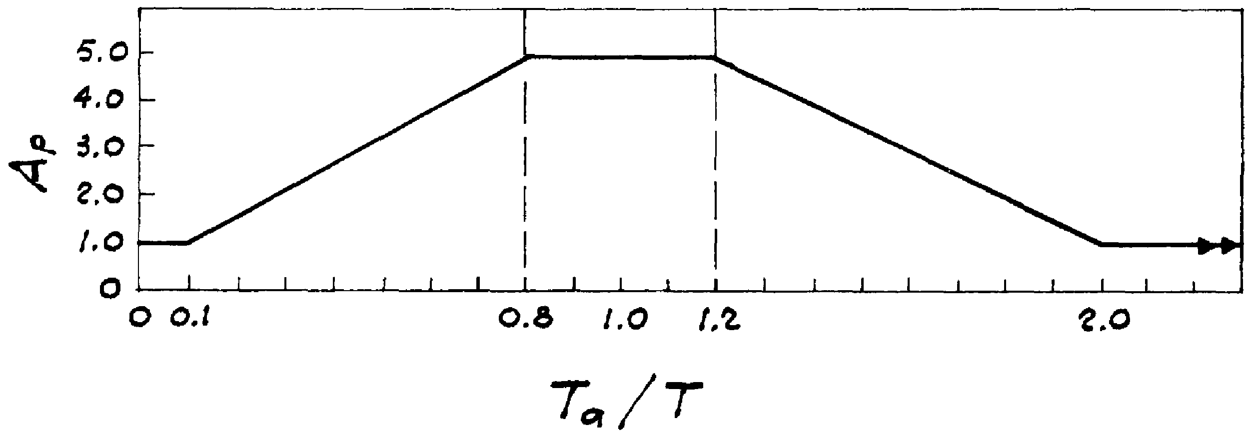
(b) In a building with T = 1.4 seconds. Use graph (b) in figure 12-3. T_a/T = 0.2/1.4 = 0.14 <1.2. Thus, A_p is equal to the value in Table 12-1; A_p = 3.7.

(5) An anchorage system is to be designed for equipment with a period T_a equal to 2.0 seconds.

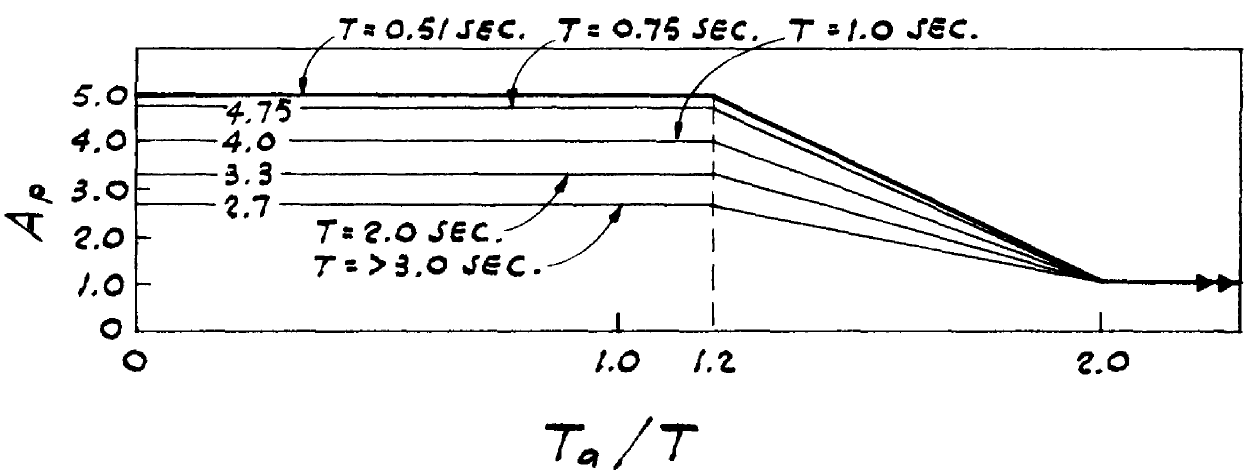
(a) In a building with T = 0.5 second. Use graph (a) in figure 12-3. T_a/T = 2.0/0.5 = 4.0, A_p = 1.0.

(b) In a building with T = 1.4 seconds. Use graph (b) in figure 12-3. T_a/T = 2.0/1.4 = 1.4. Interpolate between the curves for T = 1.0 seconds and T = 2.0 seconds. A_p = 3.0.

g. Lateral bracing. Stiffening of the equipment supports by lateral bracing may be used to reduce the appendage period, thus possibly reducing the design seismic loads. Lateral bracing for compression members expressly designed for seismic forces will not exceed the slenderness limitation of L/r < 200 in any direction. L is the unbraced length



(a) When the fundamental period of the building is equal or less than 0.5 seconds ($T \leq 0.5$).



(b) When the fundamental period of the building is greater than 0.5 seconds ($T > 0.5$). (Note: If $T_a/T < 1.2$, A_p is equal to value obtained from Table 12-1 .)

Figure 12-3. Amplification factor, A_p, for nonrigid and flexibly supported equipment.

in inches in the direction considered, and r is the corresponding radius of gyration in inches.

h. Storage tank hydrodynamic effects. Storage tanks in which the liquid is rigidly contained need not have hydrodynamic effects included in the seismic design when using the equivalent static force procedure. However, when the sloshing effects of the liquid could be detrimental to the function of the tank, the hydrodynamic effects will be considered. Refer to chapter 13 for guidance in utilizing established principles of fluid mechanics and structural dynamics.

12-5. Equipment on the ground. Equipment on the ground is defined as equipment that is laterally self-supported at or below ground level (SEAOC 1G2d). It may be in contact with or buried in the soil; supported by means of a slab, footing, or pedestal directly supported by the soil; or supported on piles embedded in the soil. Such equipment may be classified in one of two general categories, depending on its size, shape, and dynamic characteristics. The general categories are relatively small, uncomplicated equipment supported on the ground and large or complex equipment that will be considered to be a nonbuilding structure.

a. Small, uncomplicated equipment. Weight and rigidity limitations of paragraph 12-2 do not apply to equipment located on the ground because such equipment responds to seismic motion in a manner similar to that of a structure and is not subjected to the additional magnification factors of similar equipment located in the elevated stories of buildings. The equivalent static lateral force is given by the equation

$$F_p = ZI_p(\beta C_p)W_p \qquad \text{(eq 12-3)}$$

which is in conformance with SEAOC equation 1-10 with the β factor prescribed by SEAOC 1G2d. However, the forces will not be less than required by SEAOC 1I. The way SEAOC has been formulated, it appears that forces given by equation 12-3 will never be less than the forces determined from SEAOC 1I unless I_p is greater than I or unless the period of the structure is sufficiently long that the value for C is significantly reduced from the not-to-be-exceeded value of 2.75 (SEAOC 1E2a). However, SEAOC 1G2d also states that the design forces may be obtained from SEAOC 1I (i.e., they need not be greater than SEAOC 1I forces). This leads to the conclusion that equipment on the ground will be designed as nonbuilding structures and will be governed by SEAOC 1I, as modified by chapter 13.

b. Large or complex equipment. For large or complex equipment, the equipment and support system are classified as nonbuilding structures and their seismic design is governed by the provisions in chapter 13.

12-6. Lighting fixtures in buildings. In addition to the requirements of the preceding paragraphs, lighting fixtures and supports will conform to the following seismic requirements in Seismic Zones 2, 3, and 4.

a. Materials and construction.

(1) Fixture supports will employ materials that are suitable for the purpose. Cast metal parts, other than those of malleable iron, and cast or rolled threads will be subject to special investigation to ensure structural adequacy.

(2) Loop and hook or swivel hanger assemblies for pendant fixtures will be fitted with a restraining device to hold the stem in the support position during earthquake motions. Pendant supported fluorescent fixtures will also be provided with a flexible hanger device at the attachment to the fixture channel to preclude breaking of the support. The motion of swivels or hinged joints will not cause sharp bends in conductors or damage to insulation.

(3) Each recessed individual or continuous row of fluorescent fixtures will be supported by a seismic resisting suspended ceiling support system and will be fastened thereto at each corner of the fixture; or will be provided with fixture support wires attached to the building structural members using two wires for individual fixtures and one wire per unit of continuous row fixtures. These support wires (minimum 12-gauge wire) will be capable of supporting four times the support load.

(4) A supporting assembly that is intended to be mounted on an outlet box will be designed to accommodate mounting features on 4-inch boxes, 3-inch plaster rings, and fixture studs.

(5) Each surface-mounted individual or continuous row of fluorescent fixtures will be attached to a seismic resisting ceiling support system. Support devices for attaching fixtures to suspended ceilings will be a locking-type scissor clamp or a full loop band that will securely attach to the ceiling support. Fixtures attached to the underside of a structural slab will be properly anchored to the slab at each corner of the fixture.

(6) Each wall-mounted emergency light unit will be secured in a manner that will hold the unit in place during a seismic disturbance.

b. Tests. In lieu of the requirements for equipment supports given in paragraph 12-4, lighting fixtures and the complete fixture supporting assembly may be accepted if they pass shaking-table tests approved by the using agency. Such tests will be conducted by an approved and independent testing laboratory, and the results of such tests will specifically state whether or not the lighting fixture supports satisfy the requirements of the approved tests. Suspension systems for light fixtures, as installed, that are free to swing a minimum of 45° from the vertical in all directions and will withstand, without failure, a force of not less than four times the weight they are intended to support will be acceptable.

12-7. Piping in buildings. Pipes are categorized as pipes related to the fire protection system, critical piping in essential and hazardous facilities, and all other piping.

a. Fire protection piping. All water pipes for fire protection systems in seismic zones 1, 2, 3, and 4 will be designed under the provisions of the current issue of the "Standard for the Installation of Sprinkler Systems" of the National Fire Protection Association (NFPA No. 13). To avoid conflict with the NFPA recommendations, the criteria in the following paragraphs are not applicable to piping expressly designed for fire protection.

b. Critical piping in essential and hazardous facilities. Critical piping is that which is required for life-safety systems, for continued operations after an earthquake, or for safety of the general public. All critical piping in essential and hazardous facilities, located in seismic zones 1, 2, 3, and 4 will be designed using the provisions in paragraph 12-7*d*.

c. All other piping.

(1) Zone 0. Piping in seismic zone 0 facilities is not required to have seismic restraints.

(2) Zone 1. Piping in seismic zone 1 facilities which are not categorized as essential or hazardous is not required to have seismic restraints.

(3) Zones 2, 3, and 4. Piping in seismic zones 2, 3, and 4 facilities not categorized as essential or hazardous is required to have seismic restraints designed using the provisions in paragraph 12-7d, except restraints may be omitted for the following installations:

(4) Gas piping less than 1 inch inside diameter.

(5) Piping in boiler and mechanical equipment rooms less than 1¼ inches inside diameter.

(6) All other piping less than 2½ inches inside diameter.

(7) All electrical conduit less than 2½ inches inside diameter.

(8) All rectangular air-handling ducts less than 6 square feet in cross-sectional area.

(9) All round air-handling ducts less than 28 inches in diameter.

(10) All piping suspended by individual hangers 12 inches or less in length from the top of pipe to the bottom of the support for the hanger.

(11) All ducts suspended by hangers 12 inches or less in length from the top of the duct to the bottom of the support for the hanger.

d. Seismic restraint provisions. Seismic restraints that are required for piping by paragraphs 12-7*b* and 12-7*c* will be designed in accordance with the following provisions.

(1) *General.* The provisions of this paragraph apply to the following:

(a) Risers. All risers and riser connections. See appendix E for a design example of a water riser.

(b) Horizontal pipe. All horizontal pipes and attached valves. For the seismic analysis of horizontal pipes, the equivalent static force will be considered to act concurrently with the full dead load of the pipe, including contents.

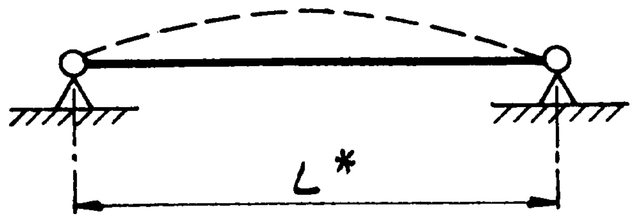
(c) Connections. All connections and brackets for pipe will be designed to resist concurrent dead and equivalent static forces. The seismic forces will be determined from the appropriate provisions below. Supports will be provided at all pipe joints unless continuity is maintained. See paragraph (4) below for acceptable sway bracing details.

(d) Flexible couplings and expansion joints. Flexible couplings will be provided at the bottoms of risers for pipes larger than 3½ inches in diameter. Flexible couplings and expansion joints will be braced laterally unless such lateral bracing will interfere with the action of the flexible coupling or expansion joint. When pipes enter buildings, flexible couplings will be provided to allow for relative movement between soil and building.

(e) Spreaders. Spreaders will be provided at appropriate intervals to separate adjacent pipe lines unless the pipe spans and the clear distance between pipes are sufficient to prevent contact between the pipes during an earthquake.

(2) *Rigid and rigidly attached piping systems.* Rigid and rigidly attached pipes will be designed in accordance with paragraph 12-3. The equivalent static lateral force is given by F_p $ZI_pC_pW_p$ (SEAOC eq 1-10), where C_p is equal to 0.75 and W_p is the weight of the pipes, the contents of the pipes, and the attachments. The forces will be distributed in proportion to the weight of the pipes, contents, and attachments. A piping system is assumed rigid if the maximum period of vibration is 0.05 second (for pipes that are not rigid see para (3) below). Figures 12-4, 12-5, and 12-6, which are based on water-filled pipes with periods equal to 0.05 second, are to be used to determine the allowable span-diameter relationship for Zones 1, 2, 3, and 4 for standard (40S) pipe; extra strong (80S) pipe; Types K, L, and M copper tubing; and 85 red brass or SPS copper pipe.

(3) *Flexible piping systems.* Piping systems that are not in accordance with the rigidity requirements of paragraph 12-7c(2) (i.e., period less than 0.05 second) will be considered to be flexible (i.e., period greater than 0.05 second). Flexible piping systems will be designed for seismic forces with consideration given to both the dynamic properties of the piping system and the building or structure in which it is placed. In lieu of a more detailed analysis, the equivalent static lateral force is given by $F = ZI_pA_pC_pW_p$ (eq 12-2), where A_p = 5.0, C_p = 0.75, and W_p is the weight of the pipes, the contents of the pipes, and the attachments. The forces will be distributed in proportion to the weight of the pipes, contents, and attachments. Figure 12-7 may be used to determine maximum spans between lateral supports for flexible piping systems. The values are based on Zone 4 water-filled pipes with no attachments. If the weight of the attachments is



DIAMETER INCHES	STD. WT. STEEL PIPE 40 S	EX. STRONG STEEL PIPE 80 S	COPPER TUBE TYPE K	COPPER TUBE TYPE L	COPPER TUBE TYPE M	85 RED BRASS & SPS COPPER PIPE
1	6'-6"	6'-6"	5'-0"	4'-9"	4'-6"	5'-6"
1½	7'-6"	7'-9"	5'-9"	5'-6"	5'-6"	6'-6"
2	8'-6"	8'-6"	6'-6"	6'-6"	6'-3"	7'-0"
2½	9'-3"	9'-6"	7'-3"	7'-0"	7'-0"	8'-0"
3	10'-3"	10'-6"	7'-9"	7'-6"	7'-6"	8'-9"
3½	11'-0"	11'-0"	8'-3"	8'-3"	8'-0"	9'-3"
4	11'-6"	11'-9"	9'-0"	8'-9"	8'-6"	9'-9"
5	12'-9"	13'-0"	10'-0"	9'-6"	9'-6"	10'-9"
6	13'-9"	14'-0"	10'-9"	10'-6"	10'-3"	11'-6"
8	15'-6"	16'-0"				
10	17'-0"	17'-6"				
12	18'-3"	19'-0"				

*MAXIMUM UNSUPPORTED OR UNBRACED LENGTHS (L) ARE BASED ON WATER-FILLED PIPES WITH PERIOD (T_a) EQUAL TO 0.05 SEC. WHERE

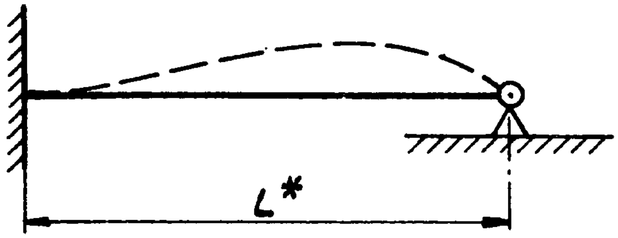
$L^2 = 0.50\pi T_a \sqrt{EIg/w}$

E = MODULUS OF ELASTICITY OF PIPE

I = MOMENT OF INERTIA OF PIPE

w = WEIGHT PER UNIT LENGTH OF PIPE AND WATER

Figure 12-4. Maximum span for rigid pipe pinned-pinned.



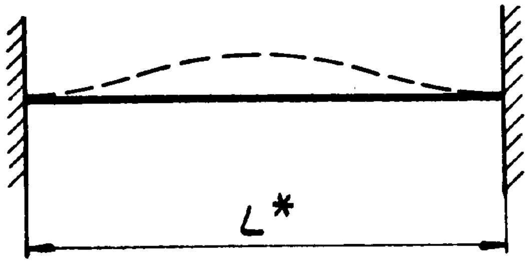
DIAMETER INCHES	STD. WT. STEEL PIPE 40 S	EX. STRONG STEEL PIPE 80 S	COPPER TUBE TYPE K	COPPER TUBE TYPE L	COPPER TUBE TYPE M	85 RED BRASS & SPS COPPER PIPE
1	8'-0"	8'-0"	6'-0"	6'-0"	5'-9"	6'-9"
1½	9'-6"	9'-6"	7'-3"	7'-0"	7'-0"	8'-0"
2	10'-6"	10'-9"	8'-0"	8'-0"	8'-9"	9'-0"
2½	11'-9"	11'-9"	9'-0"	8'-9"	8'-6"	9'-9"
3	12'-9"	13'-0"	9'-9"	9'-6"	9'-3"	10'-9"
3½	13'-6"	14'-0"	10'-6"	10'-3"	10'-0"	11'-6"
4	14'-6"	14'-9"	11'-0"	11'-0"	10'-9"	12'-3"
5	16'-0"	16'-3"	12'-3"	12'-0"	11'-9"	13'-3"
6	17'-0"	17'-9"	13'-6"	13'-0"	12'-9"	14'-3"
8	19'-3"	20'-0"				
10	21'-3"	22'-0"				
12	23'-0"	23'-6"				

*MAXIMUM UNSUPPORTED OR UNBRACED LENGTHS (L) ARE BASED ON WATER-FILLED PIPES WITH PERIOD (T_a) EQUAL TO 0.05 SEC. WHERE

$$L^2 = 0.78\pi T \sqrt{EIg/w}$$

SEE FIGURE 12-4 FOR NOTATIONS

Figure 12-5. Maximum span for rigid pipe fixed-pinned.



DIAMETER INCHES	STD. WT. STEEL PIPE 40S	EX. STRONG STEEL PIPE 80S	COPPER TUBE TYPE K	COPPER TUBE TYPE L	COPPER TUBE TYPE M	85 RED BRASS & SPS COPPER PIPE
1	9'-6"	9'-6"	7'-3"	7'-3"	7'-0"	8'-0"
1½	11'-6"	11'-6"	8'-6"	8'-6"	8'-3"	9'-9"
2	12'-9"	13'-0"	9'-9"	9'-6"	9'-6"	10'-9"
2½	14'-0"	14'-3"	10'-9"	10'-6"	10'-6"	11'-9"
3	15'-6"	15'-9"	11'-9"	11'-6"	11'-3"	13'-0"
3½	16'-6"	16'-9"	12'-6"	12'-3"	12'-0"	14'-0"
4	17'-3"	17'-9"	13'-6"	13'-0"	13'-0"	14'-9"
5	19'-0"	19'-6"	15'-0"	14'-6"	14'-3"	16'-0"
6	20'-9"	21'-3"	16'-3"	15'-9"	15'-6"	17'-3"
8	23'-3"	24'-3"				
10	25'-9"	26'-6"				
12	27'-6"	28'-6"				

* MAXIMUM UNSUPPORTED OR UNBRACED LENGTHS (L) ARE BASED ON WATER-FILLED PIPES WITH PERIOD (T_a) EQUAL TO 0.05 SEC. WHERE

$$L^2 = 1.125\pi\, T_a \sqrt{EIg/w}$$

SEE FIGURE 12-4 FOR NOTATIONS

Figure 12-6. Maximum span for rigid pipe fixed-fixed.

greater than 10 percent of the weight of the pipe, the attachments will be separately braced, or substantiating calculations will be required. Temperature stresses have not been considered in figure 12-7. If temperature stresses are appreciable, substantiating calculations will be required.

(a) Use of figure 12-7. The maximum spans and design forces were developed for $ZI_pA_pC_p = 1.50$. For lower $ZI_pA_pC_p$ values, the spans and forces may be adjusted by the values in table 12-2.

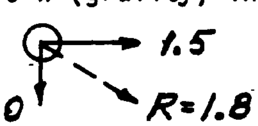
(b) Separation between pipes. Separation will be a minimum of four times the calculated maximum displacement due to F_p, but not less than 4 inches clear between parallel pipes, unless spreaders are provided (para 12-7*c*(1)(*e*)).

(c) Clearance. Clearance from walls or rigid elements will be a minimum of three times the calculated displacement due to F_p, but not less than 3 inches clear from rigid elements.

(4) Alternative method for flexible piping systems. If the provisions in the above paragraphs appear to be too severe for an economical design, alternative methods based on the rationale described in paragraph 12-4 and paragraph 12-8 may be applied to flexible piping systems.

Diameter (in.)	Std. Wgt. Steel Pipe - 40S		Ex. Strong Steel Pipe - 80S		Copper Tube Type L	
	L*(ft)	F†(lbs)	L*(ft)	F†(lbs)	L*(ft)	F†(lbs)
1	22	70	22	80	11	17
1-1/2	25	140	26	180	12	35
2	29	220	30	290	14	70
2-1/2	32	380	33	460	15	110
3	34	550	35	710	17	150
3-1/2	36	730	38	930	18	220
4	39	960	40	1,200	19	300
5	41	1,440	44	1,900	20	470
6	45	2,120	46	2,750	22	730
8	49	3,740	54	5,150	26	1,550
10	54	6,080	59	7,670	28	2,620
12	58	8,560	61	10,350	31	3,950

*Maximum spans (L) between lateral supports of flexible piping are based on the resultant of an assumed loading of 1.5 w ($ZI_pA_pC_p$ = 1.5) in the horizontal direction and 1.0 w (gravity) in the vertical direction. The resultant is 1.8 w.



The assumed maximum stress is 20,000 p.s.i. for steel and 7,000 p.s.i. for copper. Simple spans (pinned-pinned) are assumed. The calculated maximum lateral displacements are 3.5 inches for steel ($E = 29 \times 10^6$ p.s.i.) and 0.6 inch for copper ($E = 15 \times 10^6$ p.s.i.).

†The horizontal force (F) on the brace is based on 1.5 w L for the maximum span. For shorter spans, $F_{design} = (L_{design}/L)F$.

Figure 12-7. Maximum span for flexible pipes in Seismic Zone 4.

Zone	L (feet)	F (pounds)	$ZI_pA_pC_p$
3	1.1	0.8	1.12
2B	1.20	0.6	0.75
2A	1.25	0.5	0.56
1	1.35	0.3	0.28

Table 12-2. Multiplication factors for figure 12-7 for Seismic Zones 1, 2, and 3 or for cases where $ZI_pA_pC_p$ is not equal to 1.5.

(5) Acceptable seismic details for sway bracing. Acceptable details are shown in figure 12-8.

12-8. Stacks. Stacks are actually beams with distributed mass and, as such, cannot be approximated accurately by single-mass systems. The design criteria presented herein apply to either cantilever or singly guyed stacks. All stacks designed under the provisions of this paragraph must have a constant moment of inertia or must be approximated as having a constant moment of inertia. Stacks having a slightly varying moment of inertia will be treated as having a uniform moment of inertia with a value equal to the average moment of inertia.

a. Stacks on buildings. Stacks that extend more than 15 feet above a rigid attachment to the building will be designed according to the criteria prescribed below. Stacks that extend less than 15 feet will be designed for the equivalent static lateral force prescribed in SEAOC equation 1-10, with C_p =2.00 (see para 12-3).

(1) *Cantilever stacks.*

(a) The fundamental period of the stack will be determined from the period coefficient (i.e., C = 0.0909) provided in figure 12-9, unless actually computed.

(b) The equivalent static force will be distributed as an inverted triangle per unit length as shown in figure 12-10.

(c) The static force per unit length at the top of the stack will be determined from the following:

$$f = 1.6ZI_pA_pC_pW \qquad \text{(eq 12-4)}$$

where

Z and I_p are defined in SEAOC 1C

C_p = 0.75

A_p = amplification factor for coefficient C_p, determined in accordance with paragraph 12-4e

w = weight per unit length of stack

In no case will the product of A_pC_p be less than 2.0. The value $I_pA_pC_p$ need not exceed 3.75.

(2) *Guyed stacks.* The analysis of a guyed stack depends on the relative rigidities of the cantilever resistance and the guy wire support systems. If the wires are very flexible, the stack will respond in the manner of the fundamental mode of vibration of a cantilever (para (1) above). If the wires are very rigid, the stack will respond in a manner similar to the higher modes of vibration of a cantilever with periods and mode shapes similar to those shown in figure 12-9. The fundamental period of vibration of the guyed system will be somewhere between the values for the fundamental and the appropriate higher mode of a similar cantilever stack. An illustration for a single-guyed stack is shown in figure 12-11. The design of guyed stacks is beyond the scope of this manual.

b. Stacks on the ground. Where the stack foundations are in contact with the ground and the stack is not supported by the building, the stack will be designed as a non-building structure in accordance with SEAOC 1I and chapter 13.

c. Anchor bolts. Anchor bolts for moment resisting stack bases should be as long as possible. A great deal more strain energy can be absorbed with long anchor bolts than with short ones. The use of these long anchor bolts has been demonstrated to give stacks better earthquake performance. In some cases, a pipe sleeve is used in the upper portion of the anchor bolt to ensure a length of unbonded bolt for strain energy absorption. When this type of detail is used, provisions will be made for shear transfer (e.g., shear keys). The use of two nuts on anchor bolts is also recommended to provide an additional factor of safety.

12-9. Bridge cranes and monorails. In addition to the normal horizontal loads prescribed by the various other applicable government criteria, the design of bridge cranes and monorails will also include an investigation of lateral seismic forces and deformations as set forth in this paragraph.

a. Equivalent static force. A lateral force equal to ZI_pC_p times the weight of the bridge crane or

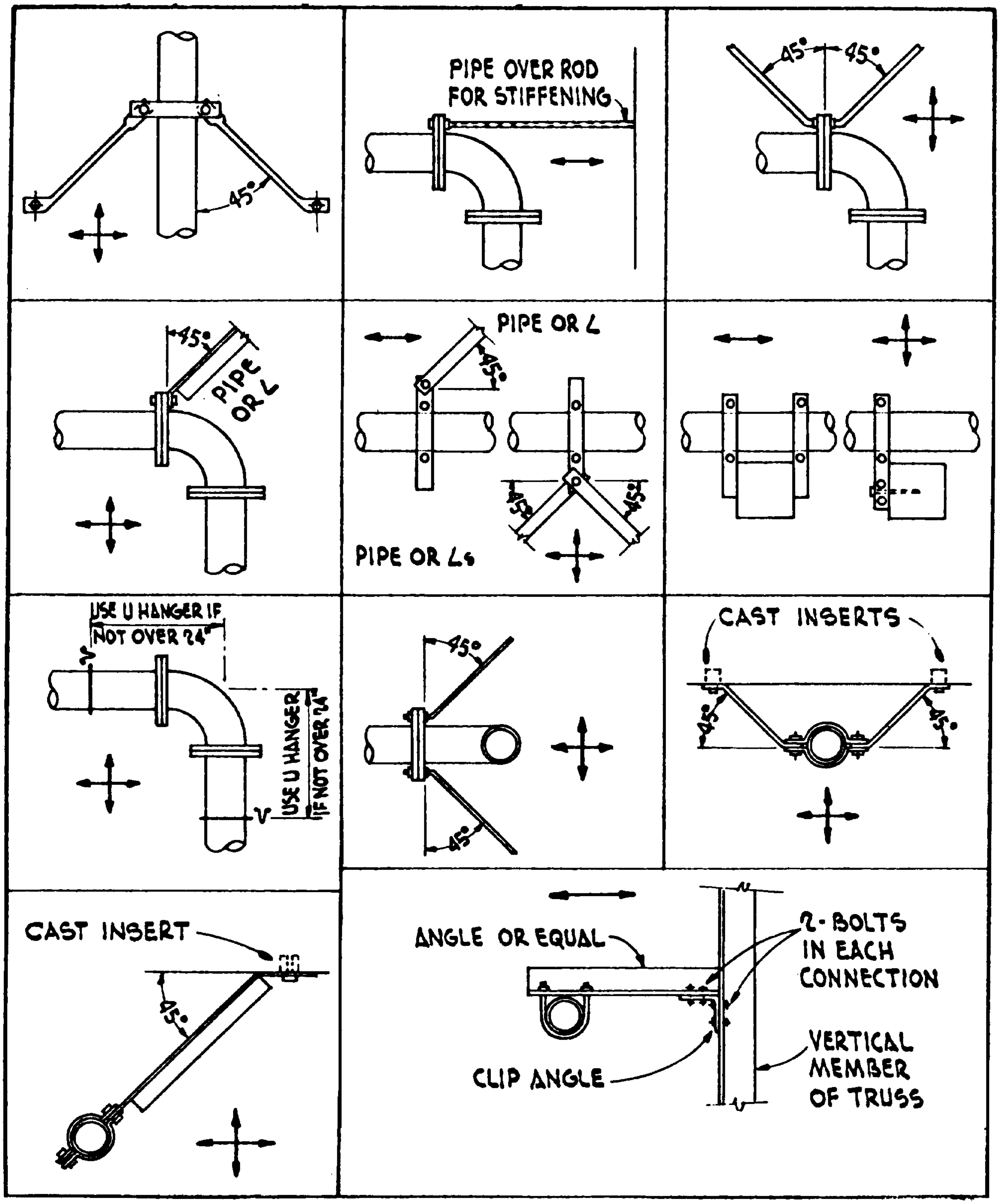


Figure 12-8. Acceptable seismic details for sway bracing.

monorail will be statically applied at the center of gravity of the equipment. This equivalent static force will be considered to be applied in any direction. will be equal to 1.50.

b. Weight of equipment. The weight of such equipment, W_p, need not include any live load, and the equivalent static force so computed will be assumed to act nonconcurrently with other prescribed nonseismic horizontal forces when considering the design of the crane and monorails. When

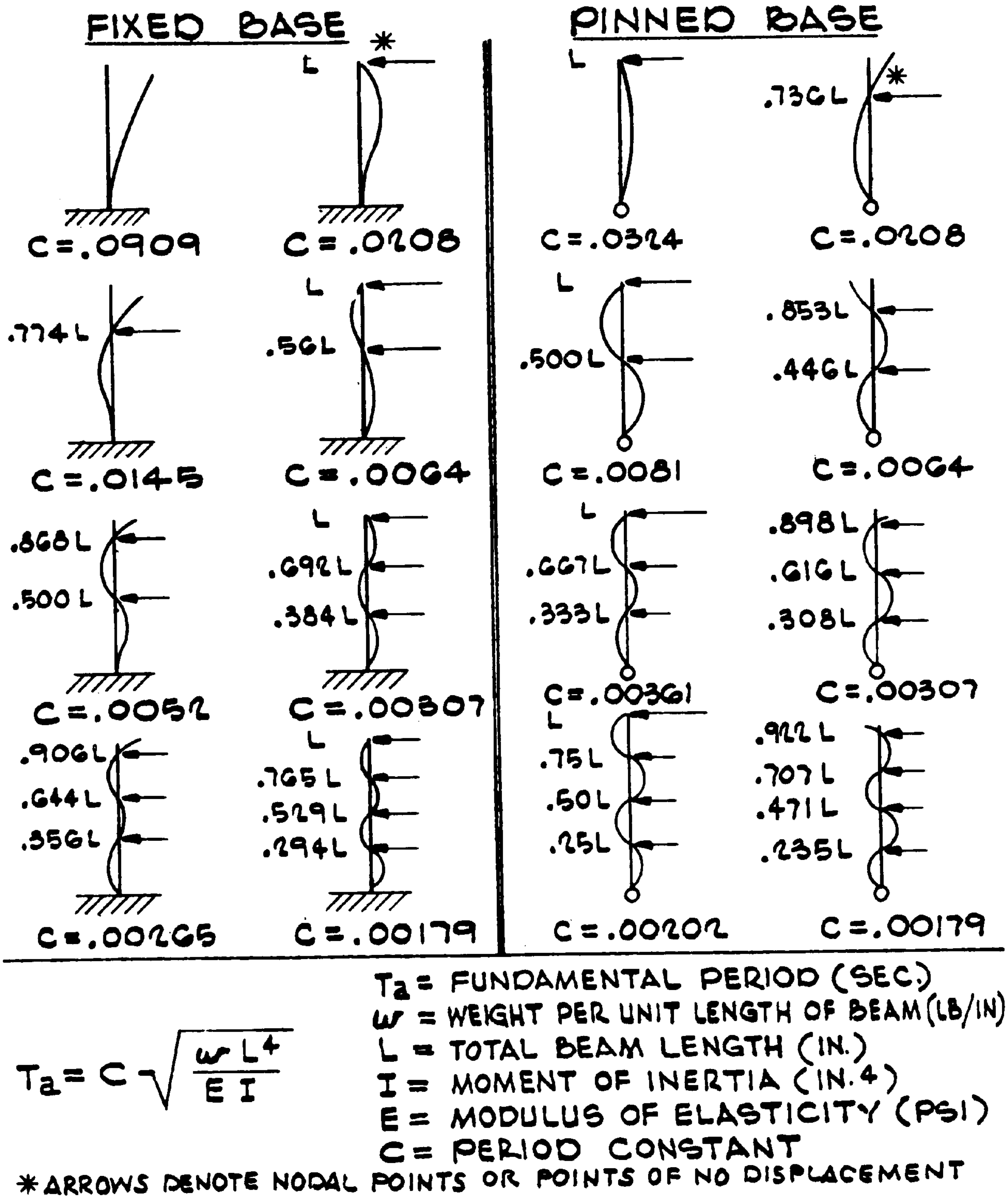


Figure 12-9. Period coefficients for uniform beams.

considering the design of the building, the weight of the equipment will be included with the weight of the building.

12-10. Elevators. Power-cable-driven elevators and hydraulic elevators with lifts over 5 feet will be designed for lateral forces set forth in this chapter.

a. Elements of the elevator support system. All elements that are part of the elevator support system, such as the car and counterweight frames, guides, guide rails, supporting brackets and framing, driving machinery, operating devices, and control equipment, will be investigated for the prescribed lateral seismic forces. See figure 12-12.

b. Equivalent static forces. The lateral seismic

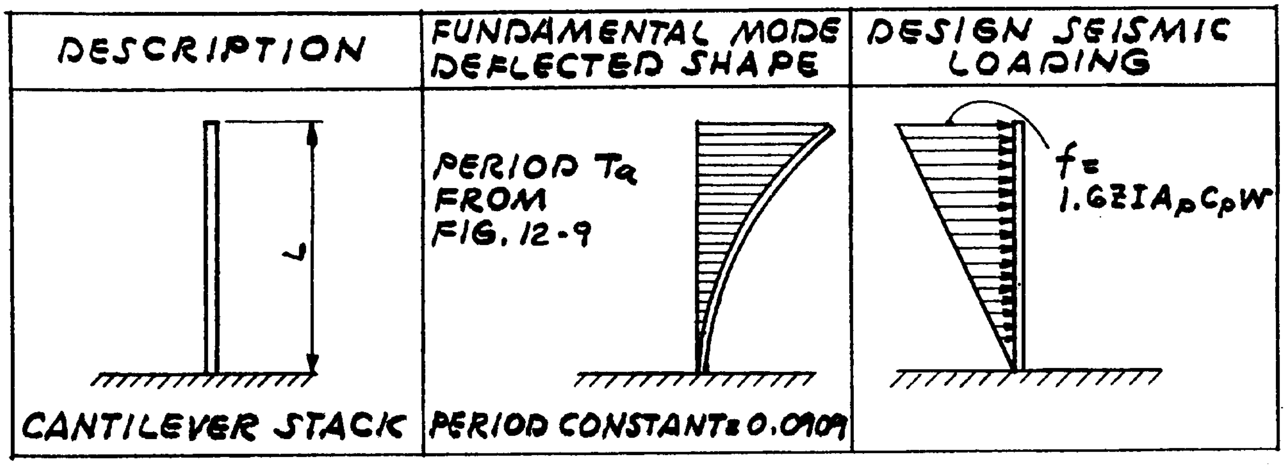


Figure 12-10. Seismic loading on cantilever stack.

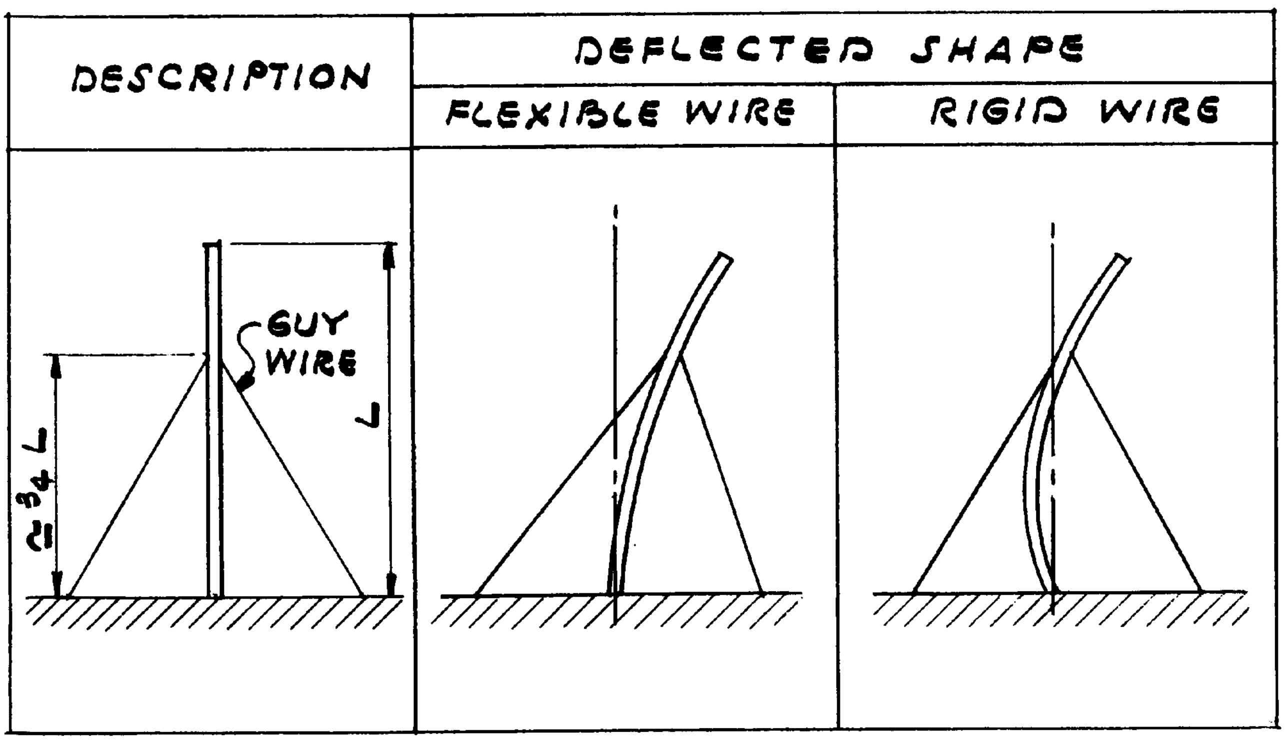
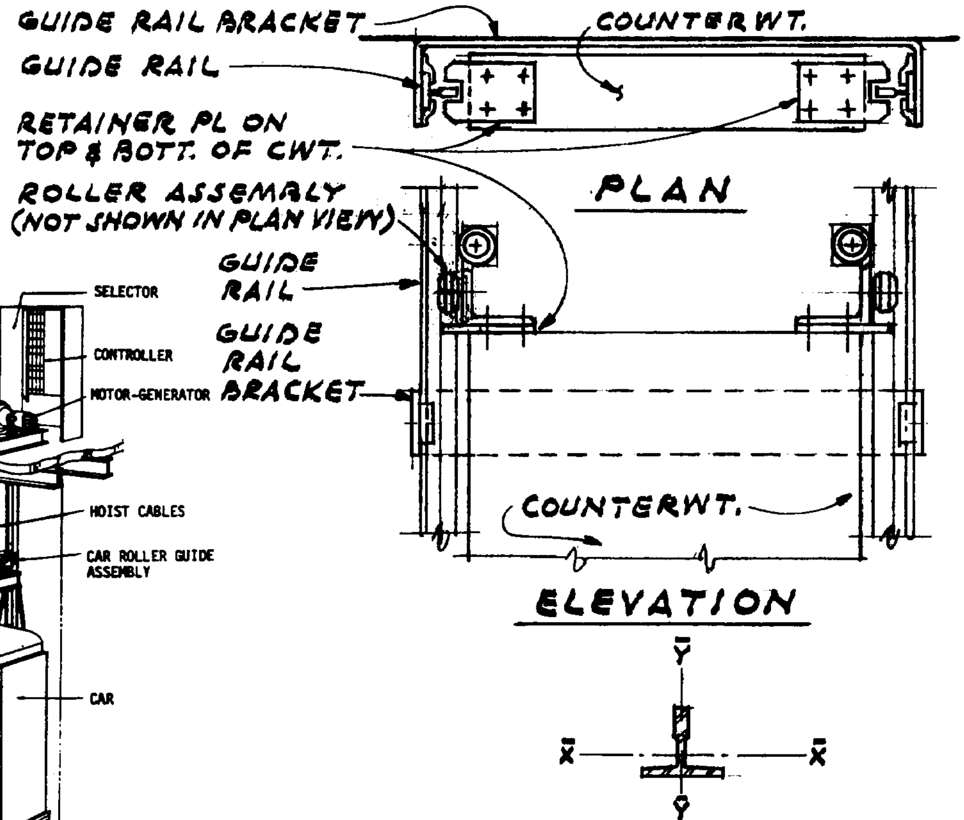


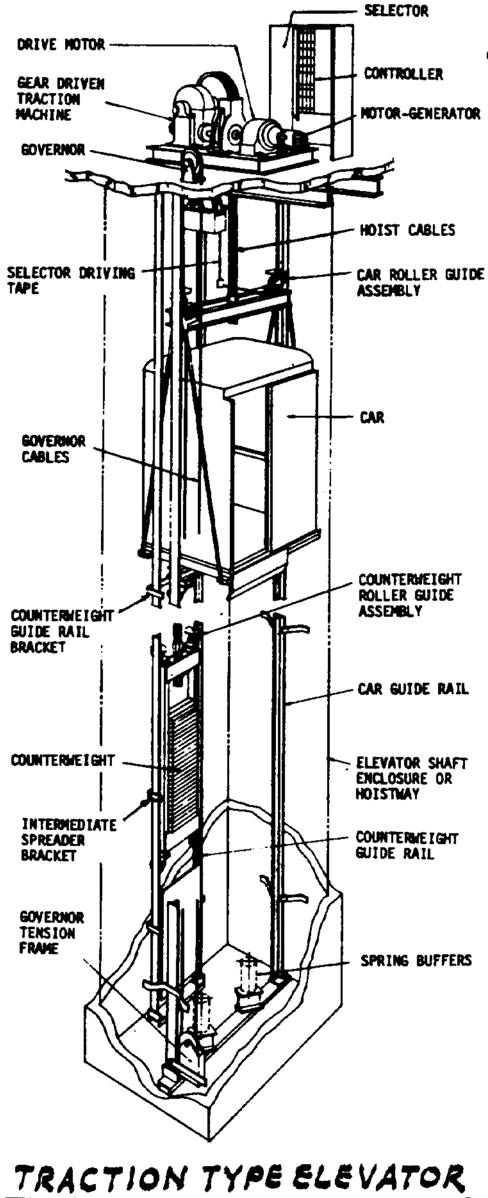
Figure 12-11. Single-guyed stack.

forces will conform to the applicable provisions of paragraphs 12-3 and 12-4 and SEAOC 1E4.

(1) The car and counterweight frames, roller guide assembly, retainer plates, guide rails, and supporting brackets and framing will be designed for $F_p = ZI_pC_pW_p$ (SEAOC eq 1-10) where W_p for the elevator cars is the weight of the car plus 0.4 times its rated load and $C_p = 0.75$. The lateral forces acting on the guide rails will be assumed to be distributed one-third to the top guide rollers and two-thirds to the bottom guide rollers of elevator cars and counterweights. The elevator car and/or counterweight will be assumed to be located at its most adverse position in relation to the guide rails and support brackets. Horizontal deflections of guide rails will not exceed ½ inch between supports, and horizontal deflections of the brackets will not exceed ¼ inch.

(a) In Seismic Zones 3 and 4, a retainer plate (auxiliary guide plate) will be provided at top and bottom of both car and counterweight. The clearances between the machined faces of the rail and the retainer plate will not be more than $^3/_{16}$ inch, and the engagement of the rail will not be less than the dimension of the machined side face of the rail. When a car safety device attached to the lower members of the car frame complies with





SECTION PROPERTIES OF ELEVATOR GUIDE RAILS

Nom. Wt. Per Foot	A	$\bar{y}$	I_x	S_x	r_x	I_y	S_y	r_y
8	2.40	.81	1.40	.86	.78	1.28	.73	.74
11	3.24	1.12	4.29	1.80	1.15	2.67	1.19	.90
12	3.51	1.08	4.49	1.85	1.13	3.61	1.45	1.01
15	4.41	.97	4.78	1.89	1.04	5.51	2.21	1.12
18.5	5.44	1.26	9.67	3.23	1.33	7.45	2.71	1.17
22.5	6.73	1.38	11.17	4.20	1.28	8.64	3.10	1.13
30	8.93	1.74	24.00	7.37	1.64	11.08	4.03	1.11

A = Area (in.^{2})
$\bar{y}$ = Distance from back of rail to axis x-x (in.)
I_x = Moment of inertia about axis x-x (in.^{4})
S_x = Section modulus about axis x-x (in.^{3})
r_x = Radius of gyration about axis x-x (in.)
I_y = Moment of inertia about axis y-y (in.^{4})
S_y = Section modulus about axis y-y (in.^{3})
r_y = Radius of gyration about axis y-y (in.)

Figure 12-12. Elevator details.

the lateral restraint requirements, a retainer plate is not required for the bottom of the car.

(b) In Seismic Zones 3 and 4, the maximum spacing of the counterweight rail tie brackets tied to the building structure will not exceed 16 feet. An intermediate spreader bracket, not required to be tied to the building structure, will be provided for tie brackets spaced greater than 10 feet, and two intermediate spreader brackets are required for tie brackets spaced greater than 14 feet.

(2) Machinery and equipment will be designed for C_p = 0.75 in equation 3-10 when rigid and

rigidly attached. Nonrigid or flexibly mounted equipment will be designed in accordance with paragraph 12-4.

12-11. Typical details for securing equipment. See figures 12-13 and 12-14 for examples of seismic restraints for equipment.

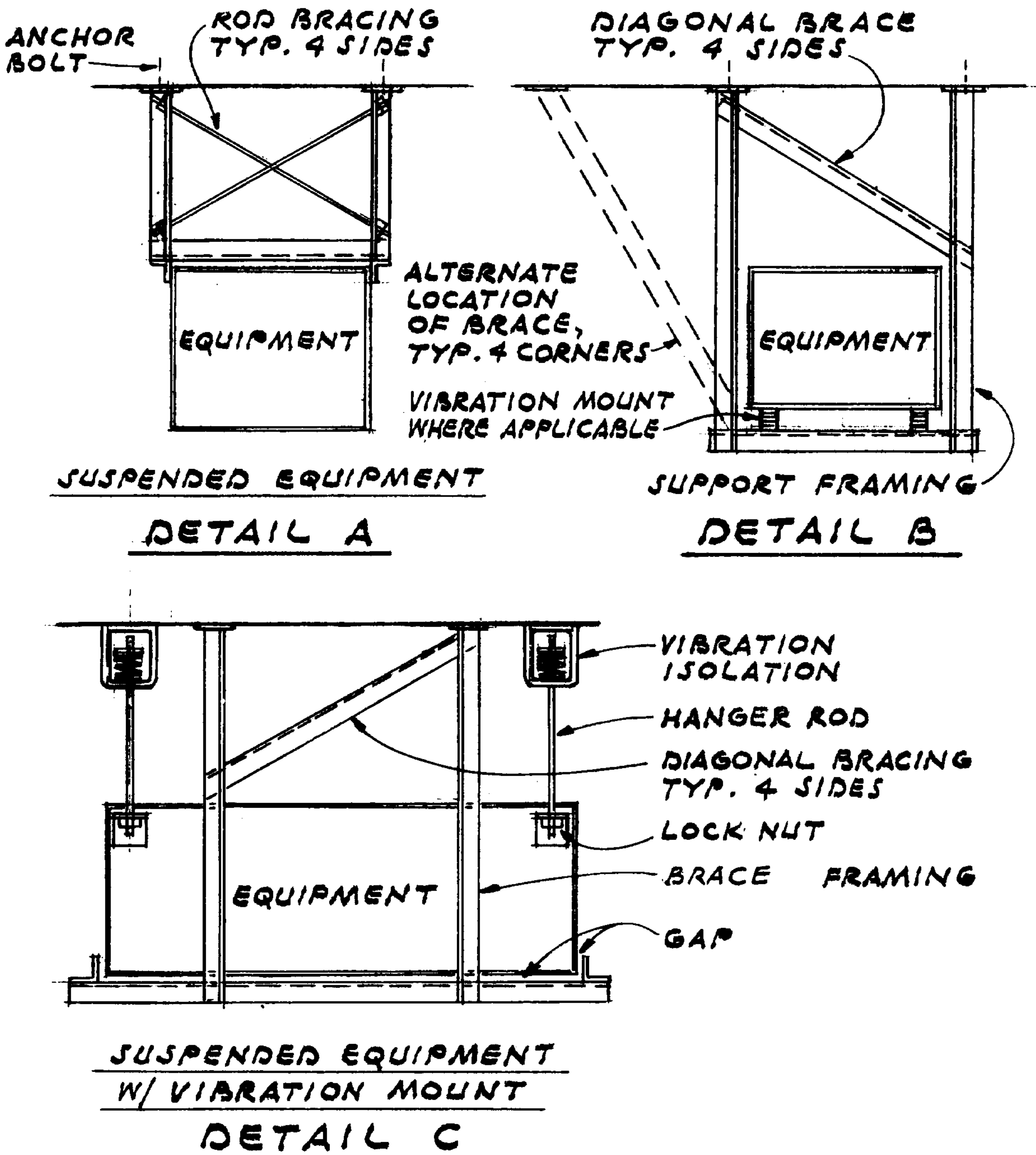


Figure 12-13. Typical seismic restraint of hanging equipment.

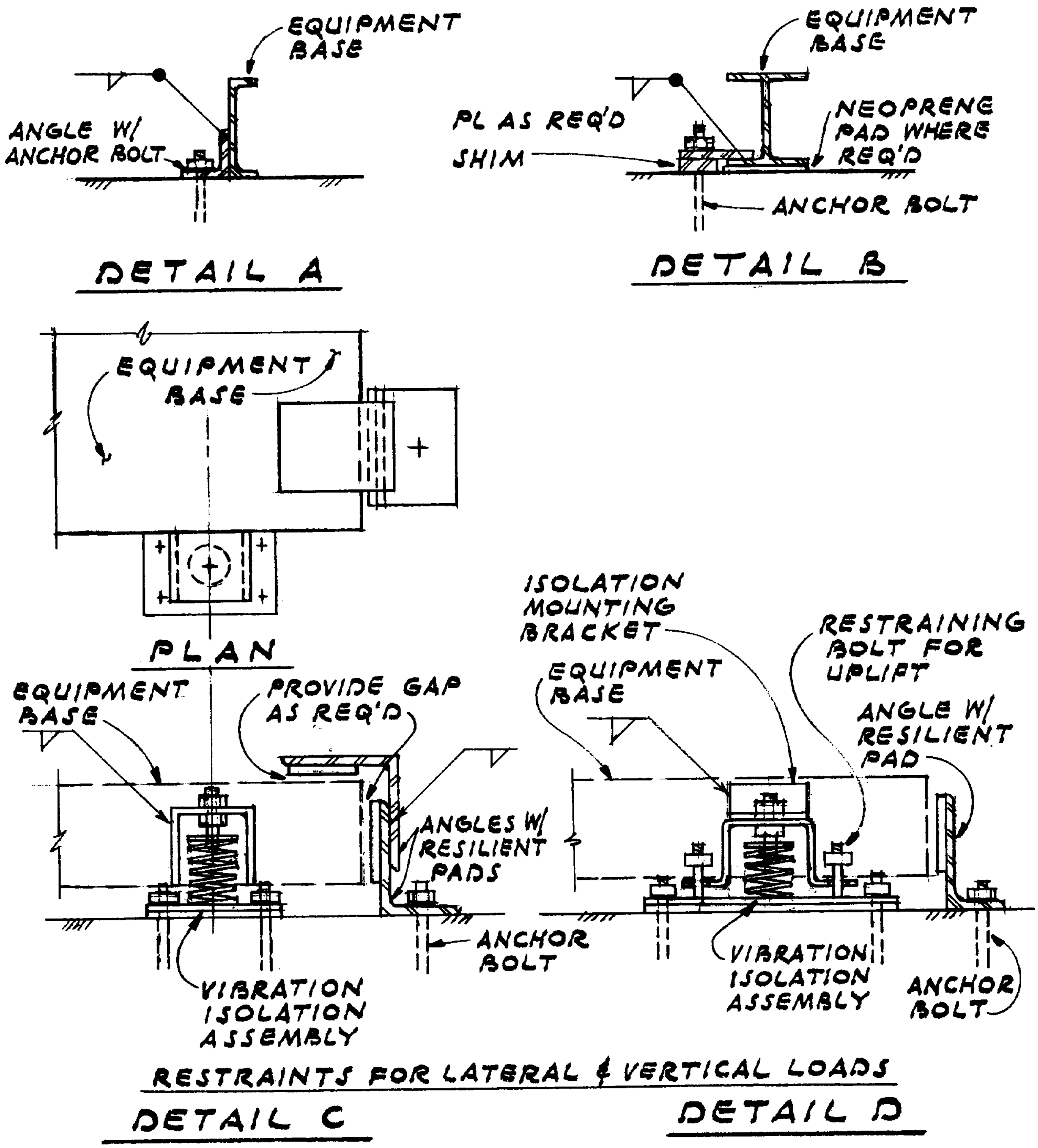


Figure 12-14. Typical seismic restraint of floor-mounted equipment.